

Determination of Adsorption Potential of Waste Tyre-Based Activated Carbon for Heavy Metal Removal

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ABSTRACT

Developing countries including Kenya, have recorded rapid growth in industrialization and population. This growth has contributed to a rise in wastewater pollution, leading to serious environmental and health risks. Paint and pigment manufacturing industries release heavy metals like lead, cadmium, and chromium into water bodies. These heavy metals threaten aquatic life and human health. Traditional treatment methods are costly and not widely used, creating a need for sustainable alternatives. This study examines the efficiency of coagulation, flocculation, and adsorption in removing heavy metals from industrial wastewater. Waste tires were carbonised at 700°C to yield activated carbon adsorbents. They were later cleaned and optimised. Coagulation-flocculation with aluminium sulphate reduced turbidity by 45.73-55.26%, however it was insufficient for heavy metal removal. The efficacy of adsorption with tire-derived activated carbon relies on pH, contact time, and adsorbent dose. However, it did not entirely fulfil EMCA criteria, pointing out the need for further enhancements. These studies demonstrate the possibility of repurposing waste materials for environmental cleaning. With further optimisation and large-scale use, tire-based activated carbon could provide a low-cost, long-term option for wastewater treatment. This will help to reduce industrial pollution and protect water sources.

Keywords: Wastewater treatment, Heavy metals, Adsorption, Coagulation-flocculation, Waste tyre recycling, Environmental pollution

INTRODUCTION

Rapid industrialization and population growth in developing nations, especially Kenya, have led to severe environmental challenges [1]. This is mainly due to poor wastewater treatment. In Nairobi's industrial area, factories discharge untreated wastewater directly into the Nairobi River [2]. As a result, neighbouring communities face serious health risks. Contaminated water has been linked to outbreaks of waterborne diseases [3], [4]. There is need for intervention.

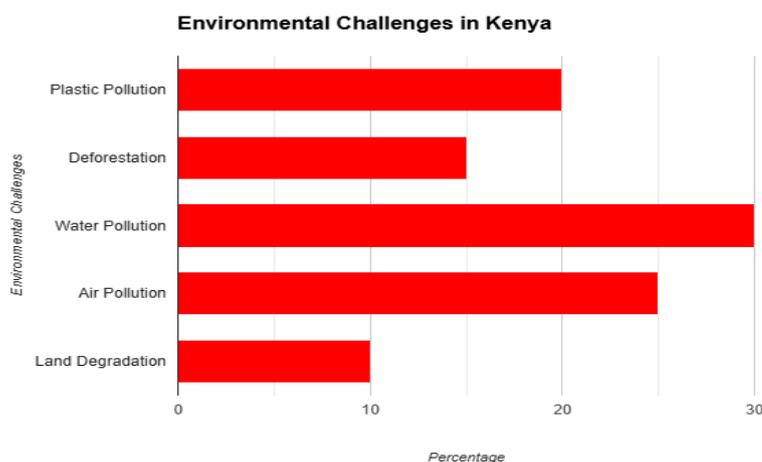


Figure 1: Chart showing environmental challenges faced in Kenya.

The growing demand for decorative and automotive coatings has driven the paint industry. The demand has greatly contributed to pollution in local waterways. Protecting Kenya’s environmental integrity is an important step towards achieving sustainable development. Firmer regulations and improved governance are required. Without better monitoring and enforcement, poor effluent treatment will continue to harm ecosystems and public health.

Based on recent studies, waste tires contain high carbon content that could be repurposed into activated carbon [5], [6]. Activated carbon can be used for wastewater treatment, providing a practical and sustainable pollution control method.

Transforming old tyres into carbon-based materials is proving to be an effective way to filter out contaminants from both industrial and household wastewater [7], [8], [5]. This approach showcases how innovative waste management solutions can support long-term sustainability efforts.

The process of transforming waste tyre into Activated Charcoal



Figure 2: Process of Transforming waste tyre into Activated Charcoal

Statement of the Problem

The release of wastewater containing heavy metals into Nairobi River is a major threat to both the environment and public health [9] [10]. Traditional treatment methods are expensive and therefore not widely used [11]. It is important to create affordable and long-term solutions. This study was done to determine whether activated carbon made from waste tyres could serve as a cost-effective alternative for reducing heavy metal contamination.

Objectives

Main Objective

This study intends to determine how well coagulation, flocculation, and adsorption work in removing heavy metal contaminants from wastewater.

Specific Objectives

- i. To determine the reduction efficiency of coagulation-flocculation in heavy metal removal.
- ii. To investigate the adsorption capacity of activated carbon derived from waste tyres.
- iii. To determine the optimal conditions for adsorption, including dosage, contact time, and pH.

MATERIALS AND METHODS

Sample Collection

Wastewater samples were collected from three paint factories located in the industrial area of Nairobi County. The samples were collected and transported to the laboratory for analysis.

Coagulant Determination

To identify the optimal coagulant dosage, an Aluminium Sulphate (Al^{3+}) solution was prepared and added to wastewater samples in varying amounts, ranging from 2 to 12 mL. The effectiveness of the coagulant was evaluated by measuring the remaining turbidity in the treated samples.

Adsorbent Preparation

The adsorbent was produced from waste tyres, which were first cut into smaller pieces and treated with potassium hydroxide (KOH). The treated material was then carbonized at $700^{\circ}C$. After carbonization, the resulting carbon was thoroughly washed with hydrochloric acid (HCl) and distilled water to remove impurities. It was then dried, finely ground, and processed into a powdered form suitable for adsorption studies.

Optimization of Adsorption Conditions

To determine the optimal adsorption conditions, different dosages of the adsorbent (ranging from 0.1 to 0.7 g) were tested in wastewater samples. The contact time between the adsorbent and wastewater was varied between 30 and 120 minutes to assess its effect on metal removal efficiency. Additionally, the pH of the samples was adjusted between 2 and 9 to identify the most favourable conditions for adsorption.



Figure 3: Image of samples prepared for Analysis

The residual heavy metal concentrations in the treated samples were analyzed using Atomic Absorption Spectroscopy (AAS) to evaluate adsorption performance as explained in the study by Kithure and Nyandieka [12].



Figure 3: Atomic Absorption Spectrometry instrument used for analysis.

The adsorption experiments showed that the removal of heavy metals by activated carbon was dependent on several factors:

- **Adsorbent Dosage:** The optimum dosage was found to be 0.5-0.6 % (w/v).
- **Contact Time:** The optimum contact time was found to be 90-105 minutes.
- **pH:** The optimum pH range was found to be 4-6.

RESULTS AND DISCUSSION

Physicochemical Properties of Wastewater

The wastewater samples showed high levels of contamination, with COD ranging from 916.77 to 1881.20 mg/L, BOD between 149.00 and 183.00 mg/L, and TSS from 6382.3 to 7395.33 mg/L. These values indicate significant organic and inorganic pollution. The levels of COD, BOD, TSS, oil and grease, total phosphorus, and total nitrogen were significantly above the limits set by Kenya's National Environmental Management Authority (NEMA), indicating severe organic and nutrient pollution.

Heavy metal concentrations were also elevated, with cadmium levels between 3.03 and 4.18 mg/L, lead ranging from 5.38 to 17.21 mg/L, and chromium between 2.07 and 3.04 mg/L. These levels surpass NEMA's permissible limits, posing a serious risk to both the environment and human health.

Parameter	Range (Mean ± SD)	Unit
pH	6.48 ± 0.14 – 6.89 ± 0.04	-
Temperature	28.07 ± 0.12 – 28.30 ± 0.12	°C
Electrical Conductivity	837.33 ± 6.66 – 881.33 ± 8.62	µS/cm
COD	916.77 ± 28.15 – 1881.20 ± 24.82	mg/L
BOD	149.00 ± 1.41 – 183.00 ± 1.41	mg/L
Total Phosphorus	145.00 ± 3.61 – 149.32 ± 1.22	mg/L
TSS	6382.3 ± 658.01 – 7395.33 ± 364.23	mg/L
Oil and Grease	3525.00 ± 17.52 – 6374.33 ± 23.03	mg/L
Total Sulphur	72.62 ± 3.11 – 73.41 ± 1.71	mg/L
Total Nitrogen	1586.67 ± 29.14 – 4442.67 ± 70.47	mg/L

Effectiveness of Coagulation-Flocculation

Turbidity reduction improved as the coagulant dosage increased, with the optimal aluminium sulphate concentration of 8–10 mg per 200 mL achieving a turbidity reduction of 45.73–55.26%.

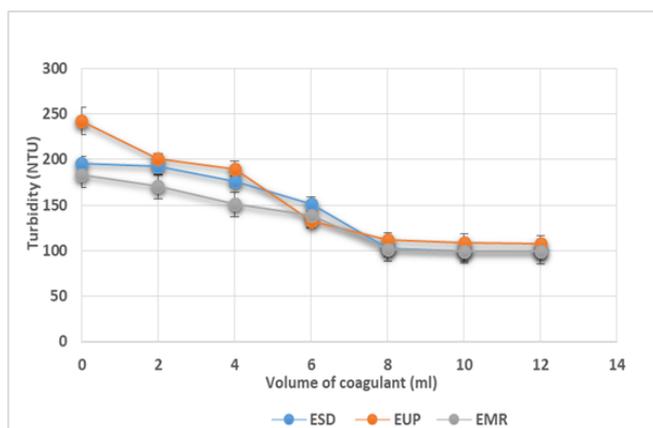


Figure 4: Results showing correspondence of waste water turbidity with increase in coagulant volume.

However, coagulation alone was not sufficient to lower heavy metal concentrations to acceptable levels.

Adsorption Performance of Waste Tyre-Derived Activated Carbon

Activated carbon derived from waste tyres showed strong potential for heavy metal removal. The adsorption efficiency improved with a higher adsorbent dosage, extended contact time, and optimal pH conditions. The highest removal efficiencies were recorded at a pH range of 4–6, with an adsorbent dosage of 0.5–0.6% (w/v) and a contact time of 90–105 minutes. The adsorption isotherm analysis showed that the Langmuir model

provided a better fit for the experimental data than the Freundlich isotherm. This suggests that heavy metal adsorption onto the activated carbon occurred as a monolayer on a homogenous surface.

CONCLUSION

This study confirms that waste tyres can be repurposed into effective adsorbents for removing heavy metals from industrial wastewater. While coagulation-flocculation helps reduce turbidity, it is not enough to lower heavy metal concentrations to safe levels. Adsorption using tyre-derived activated carbon offers a cost-effective and sustainable alternative for further purification.

The results showed that adsorption performance depended on factors such as pH, contact time, and adsorbent dosage, with the Langmuir isotherm model best describing the adsorption process. This suggests that heavy metal removal occurred as a monolayer on a uniform surface, highlighting the efficiency of the adsorbent.

However, further improvements are needed to enhance adsorption capacity and ensure the treated water meets environmental standards. Future research could explore ways to modify the adsorbent for better performance and assess its long-term effectiveness in large-scale applications. Overall, this approach not only provides a solution for wastewater treatment but also promotes the recycling of waste tyres, contributing to both environmental protection and resource sustainability.

RECOMMENDATIONS

The findings of this study highlight the potential of waste tyre-derived activated carbon as a cost-effective solution for heavy metal removal from industrial wastewater. To enhance its application and improve wastewater management, the following recommendations are proposed:

Improving Activated Carbon Production

Refining activation processes such as temperature control and chemical treatment can enhance adsorption efficiency. Performance may be improved further by exploring alternative activation methods.

Scaling Up for Industrial Application

Pilot studies should assess the feasibility of large-scale use, focusing on cost, efficiency, and practical implementation in wastewater treatment.

Enhancing Industrial Wastewater Treatment

Paint manufacturers should integrate adsorption-based methods to improve wastewater quality and comply with environmental regulations.

Strengthening Regulations and Policies

Collaboration with policymakers and regulatory bodies is essential to incorporate tyre-derived adsorbents into treatment guidelines and ensure stricter enforcement by NEMA.

Encouraging Sustainable Practices

Repurposing waste tyres for wastewater treatment supports circular economy principles, reducing waste while providing a low-cost, eco-friendly solution.

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